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AN INVESTIGATION AT TRANSONIC SPEEDS OF THE EFFECTS OF  
FENCES, DROOPED NOSE, AND VORTEX GENERATORS ON THE  
AERODYNAMIC CHARACTERISTICS OF A WING-FUSELAGE  
COMBINATION HAVING A 6-PERCENT-THICK,  
45° SWEEPBACK WING

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## RESEARCH MEMORANDUM

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## SUMMARY

An investigation has been made at transonic speeds to determine the effects of fences, drooped nose, combination fences and drooped nose, and vortex generators on the aerodynamic characteristics of a 45° sweptback wing-fuselage configuration. The wing has an aspect ratio of 4, a taper ratio of 0.6, NACA 65A006 airfoil sections parallel to the plane of symmetry, and no geometric twist, dihedral, or incidence. The tests were conducted in the Langley 16-foot transonic tunnel at Mach numbers from 0.60 to 1.03.

The results show that the fences increased the lift coefficient at which adverse pitching-moment changes occurred in the Mach number range from 0.60 to about 0.90 and at Mach numbers above 0.98. Drooping the forward 14 percent of the airfoil 3° from the 0.65-semispan stations to the tip increased the lift coefficient at which undesirable pitching-moment changes occurred at Mach numbers of 0.98 and 1.00. A combination of the fences and drooped nose improved the pitching-moment characteristics at all Mach numbers where beneficial effects were realized from either of the individual configurations. The drooped-nose configuration was more effective than the fences in increasing the lift-drag ratio. The vortex generators installed at the wing leading edge or at the 0.15 chordwise station resulted in no significant improvement in the pitching-moment characteristics.

## INTRODUCTION

An undesirable characteristic of relatively thin sweptback wings at subsonic and transonic speeds is the "pitch-up" tendency which results from the leading-edge vortex-type flow and consequent separation of the flow over the outboard portion of the wing as described in reference 1. In an attempt to alleviate this condition, various wing modifications have been investigated. A summary of low-speed investigations incorporating fences, various flap configurations, slats, and boundary-layer control is given in reference 2. At high subsonic and transonic speeds the effects of twist and camber (ref. 3) and several configurations of leading-edge chord-extensions (ref. 4) on the longitudinal characteristics of sweptback wings have been studied.

The present investigation, conducted in the Langley 16-foot transonic tunnel, presents some of the aerodynamic characteristics of a  $45^\circ$  sweptback wing-fuselage combination incorporating fences, drooped nose, combination fences and drooped nose, and vortex generators. The chief purpose of each of these modifications was to improve the pitching-moment characteristics only, except in the case of the drooped nose, which was installed for the purpose of improving the lift-drag ratio also.

The wing, which was mounted on a sting-supported body, has an aspect ratio of 4, a taper ratio of 0.6, and NACA 65A006 airfoil sections parallel to the plane of symmetry.

Tests with the fences and drooped nose covered an angle-of-attack range from  $-2^\circ$  to  $26^\circ$  and Mach numbers from 0.60 to 1.03. With the vortex generators installed, data were obtained at angles of attack from  $6^\circ$  to  $26^\circ$  and Mach numbers from 0.60 to 0.94. The test Reynolds number varied from about  $4.8 \times 10^6$  to  $6.6 \times 10^6$ .

## SYMBOLS

$C_L$	lift coefficient, $Lift/qS$
$C_D$	drag coefficient, $Drag/qS$
$C_m$	pitching-moment coefficient about $1/4$ mean aerodynamic chord, $Pitching\ moment/qS\bar{c}$
$L/D$	lift-drag ratio

$\alpha$	angle of attack of model
$c$	wing chord at any spanwise station
$\bar{c}$	mean aerodynamic chord, $\frac{2}{S} \int_0^{b/2} c^2 dy$
$b$	wing span
$S$	wing area
$q$	free-stream dynamic pressure
$M$	free-stream Mach number
$y$	lateral distance measured perpendicular to plane of symmetry

#### MODEL AND APPARATUS

Basic model.- The steel wing, which has no geometric twist or dihedral, has  $45^\circ$  of sweepback of the 1/4-chord line, an aspect ratio of 4, a taper ratio of 0.6, and NACA 65A006 airfoil sections parallel to the plane of symmetry and was mounted at zero incidence with respect to the body. The model was sting-supported through a six-component internal electrical strain-gage balance. The principal dimensions of the model, including a table of fuselage coordinates, are given in figure 1. A photograph of the basic model mounted in the Langley 16-foot transonic tunnel is shown as figure 2.

Fences.- Fences were installed, one on each wing panel at the 0.65-semispan station, parallel to the model longitudinal axis. They extended 0.09 local chord above the wing chord line and about  $1\frac{11}{16}$  inches (about 0.10 of the local chord) ahead of the leading edge. The top of each fence was parallel to the wing chord line and the bottom was shaped to fit the wing upper-surface contour. A sketch showing the fences installed on the wing is given as figure 3.

Drooped nose.- The drooped nose consisted of  $3^\circ$  droop of the forward 14 percent of the airfoil sections from the 65-percent-semispan stations to the tips as shown in figure 4.

Vortex generators.- Vortex generators spaced 1/2 inch (about 0.014 semispan) apart spanwise beginning at the wing-fuselage juncture were arranged in configurations given in the following table:

Configuration designation	Chordwise location of vortex-generator leading edge	Size, percent of mean aerodynamic chord	Spanwise extent	Angle to free stream, deg
A	Leading edge	1.02 square	Root to tip	15
B	Leading edge	1.70 square	Root to tip	15
C	Leading edge	1.70 square	Root to 0.70b/2	15
D	Leading edge	1.70 square	Root to 0.70b/2	25
E	15 percent chord	1.70 square	Root to tip	15
F	15 percent chord	1.70 square	Root to 0.70b/2	15
G	15 percent chord	1.70 square	Root to 0.50b/2	15

The chord line of the vortex generators pointed outward with respect to the model plane of symmetry as can be seen on the sketch of figure 5. A photograph of one of the configurations is shown as figure 6.

Tunnel.— The Langley 16-foot transonic tunnel, in which the present tests were conducted, has an octagonal slotted test section permitting a continuous variation in speed to Mach numbers slightly above 1.0. A complete description of the tunnel is given in reference 5.

## TESTS AND ACCURACY

### Tests

Simultaneous measurements of lift, drag, and pitching moment were obtained at Mach numbers from 0.60 to 1.03 for the model with the fences, drooped nose, and combination fences and drooped nose. The angle of attack was varied at each Mach number between the limits of  $-2^\circ$  and  $26^\circ$  at  $M = 0.60$  and between  $-2^\circ$  and  $8^\circ$  at  $M = 1.03$ .

For the vortex-generator configurations designated A, D, E, and F lift, drag, and pitching-moment data were obtained at a Mach number of 0.60 and angles of attack from  $6^\circ$  to  $26^\circ$ . For the configurations designated A, B, C, and D lift, drag, and pitching-moment measurements were obtained at a Mach number of 0.94 at angles of attack from  $6^\circ$  to  $14^\circ$ . The same components were measured for configurations E, F, and G at a Mach number of 0.90 and angles of attack from  $6^\circ$  to  $16^\circ$ . The variation of test Reynolds number (based on mean aerodynamic chord) with Mach number is given in figure 7. The base pressure coefficients for the basic model are presented in reference 6, and since the various

wing modifications should not influence the base pressures the coefficients are not repeated in this paper.

### Accuracy of Measurements

The measurement of Mach number in the test region is believed to be accurate within  $\pm 0.005$  (ref. 5). The model angle of attack was obtained from the static angle of attack corrected for deflections due to load. These deflections, which occurred in the balance and sting, were determined from a static calibration under applied normal loads and pitching moments. The resulting angle measurements obtained during the tests, neglecting tunnel air-stream alinement, are believed to be accurate within  $\pm 0.1^\circ$ . Flow surveys indicate that no stream-angle corrections are necessary for large sting-mounted models such as the one used for the present tests.

No adjustments for sting interference, model-base pressures, or aeroelasticity have been applied to the aerodynamic forces and moments. It is believed that boundary interference effects are generally negligible in this slotted wind tunnel and no attempt to correct the data for these effects has been made. Neglecting these various possible sources of error, the accuracy of the measured coefficients, based on balance accuracy and repeatability of data, is believed to be within the following limits:

$C_L$ . . . . .	$\pm 0.01$
$C_D$	
At low lift coefficients . . . . .	$\pm 0.001$
At high lift coefficients . . . . .	$\pm 0.005$
$C_m$ . . . . .	$\pm 0.005$

## RESULTS AND DISCUSSION

### Test Results

The lift, drag, and pitching-moment characteristics for the model with fences, drooped nose, and combination fences and drooped nose are presented in figure 8 at Mach numbers from 0.60 to 1.03. For comparison purposes the characteristics of the basic model, taken from reference 6, are included in the figure. The effect of the fences, drooped nose, and combination fences and drooped nose on the lift-drag ratio is given in figure 9. The variation of pitching-moment coefficient with lift coefficient only is presented for the vortex-generator configurations (fig. 10). In order to show the effect of the vortex generators, the basic model data are shown in this figure also.

### Discussion

#### Fences, drooped nose, and combination fences and drooped nose.-

As shown by the lift curves of figure 8, installation of the fences, drooped nose, or combination fences and drooped nose had little effect on the model lift coefficient or lift-curve slope. The lift-drag polars show that incorporation of any of these modifications generally reduced the drag slightly at lift coefficients above about 0.40. Addition of the fences alone increased the minimum drag coefficient by approximately 0.002 throughout the Mach number range, whereas the drooped nose had essentially no effect on minimum drag up to a Mach number of about 0.98. At the higher Mach numbers the minimum drag was increased slightly by the drooped nose. The combined modifications (fences and drooped nose) served to increase the minimum drag coefficient by about 0.002 at all Mach numbers tested mainly because of the drag added by the fences.

The lift coefficient at which adverse pitching-moment changes (pitch-up) occurred was increased by about 0.3 at a Mach number of 0.60 with the fences installed (fig. 8). This lift increment was only about 0.15 at a Mach number of 0.85 and decreased to zero at a Mach number of 0.90. Apparently the fences served as an effective boundary containing the leading-edge vortex flow which contracts outward with increasing angle of attack. The boundary-layer thickness over the outboard portions of the wing was probably reduced, thereby delaying separation to a higher lift coefficient. As the angle of attack was increased beyond initial separation, stalling over the outboard portions of the wing was probably caused by separation induced by a leading-edge vortex flow originating just outboard of the fences. At Mach numbers from about 0.90 to about 0.98 there was no increase in the lift coefficient at pitch-up due to the fences. In this Mach number range, stalling over the outboard portion of the wing due to separation at the tip was probably caused by both a shock near the leading edge following a supersonic expansion, such as described in reference 7, and the shock originating at the juncture of the fuselage and the wing trailing edge (ref. 8). The fences apparently are not effective in reducing shock-induced separation, and therefore do not improve the pitching-moment characteristics at Mach numbers from about 0.90 to 0.98. With increases in Mach number above 0.98, the trailing-edge juncture shock sweeps rearward (ref. 8), thereby affecting a smaller portion of the wing chord, and because of the reduced boundary-layer thickness at the tip resulting from the fences, separation does not spread forward as far in the boundary layer. These phenomena result in a smaller loss in lift at the tip and therefore delay the pitch-up tendency (figs. 8(f) and 8(g)). Unfortunately, limiting loads on the sting support strut would not permit testing at higher angles of attack at Mach numbers of 1.0 and 1.03, and, therefore, the full extent of the improvement in pitching-moment characteristics due to the fences could not be ascertained.

The drooped nose apparently has no effect on the vortex-type flow and, therefore, does not reduce early tip stalling at Mach numbers up to about 0.98 (fig. 8). At Mach numbers from 0.98 upward, the vortex flow has contracted outward and rearward so that severe separation is confined to the region behind the wing trailing-edge juncture shock which has swept rearward, and the drooped nose then becomes effective in delaying pitch-up (figs. 8(f) and 8(g)). As in the case of the fences, limitations of the angle-of-attack range precluded the possibility of determining the full extent of the benefits to pitching-moment characteristics resulting from the drooped nose at Mach numbers of 1.0 and 1.03.

Utilizing both the fences and drooped nose combines the beneficial pitching-moment characteristics realized from the individual configurations (fig. 8). The lift coefficient at which adverse pitching-moment characteristics occur is increased as a result of the fences at Mach numbers from 0.60 to about 0.90, whereas no beneficial effects are shown at Mach numbers from about 0.90 to about 0.98. Improved pitching-moment characteristics resulted from the gains realized by both the fences and drooped nose at Mach numbers of 0.98 and 1.00 (figs. 8(f) and 8(g)).

The effect of the fences, drooped nose, and combination of the two modifications on the lift-drag ratio is shown in figure 9. The drooped-nose configuration was more effective than the fences in increasing the lift-drag ratio. In general, the values of  $L/D$  resulting from the combination of the two modifications were between those for the individual configurations, especially at the higher Mach numbers. At the lowest Mach number tested ( $M = 0.60$ ) all modifications increased the lift-drag ratio at lift coefficients above about 0.40, whereas a decrease in  $L/D$  resulted at lower lift coefficients.

Vortex generators.— Vortex generators were installed at the leading edge of the wing in an attempt to eliminate or weaken the leading-edge vortex-type flow. The purpose of the vortex generators was to create vortices opposite in direction to the wing leading-edge vortex, thereby cancelling or reducing the magnitude of the latter vortex. It was thought that if the foregoing purpose could be accomplished, the undesirable separation at the tip and the premature tip stalling could be reduced, especially at Mach numbers up to about 0.90.

The pitching-moment data at a Mach number of 0.60 given in figure 10 show that the presence of the generators along the leading edge at either  $15^\circ$  or  $25^\circ$  to the stream (configurations A and D) delayed the pitch-up to only a very slightly higher lift coefficient (approximately 0.05). With the generators at the 0.15 chordwise station (configurations E and F) the same small increase in lift coefficient at pitch-up resulted. It is therefore concluded that tip stalling was essentially

unaffected by these configurations of vortex generators. Apparently the generators created vortices which were too weak to be effective, or they were too large and created vortices outside the boundary layer in which case they would have no effect on the wing leading-edge vortex flow which originates within the boundary layer.

At higher Mach numbers ( $M = 0.90$  and  $0.94$ ) the model pitching-moment characteristics were essentially unchanged by any of the configurations of vortex generators tested, indicating that the effects of the wing shocks were not appreciably changed.

### CONCLUSIONS

The results of an investigation at transonic speeds to determine the effects of fences, drooped nose, combination fences and drooped nose, and vortex generators on the aerodynamic characteristics of a  $45^\circ$  sweptback wing-fuselage combination are as follows:

1. Fences installed at the 0.65 semispan stations of the wing increased the lift coefficient at which pitch-up occurred by about 0.30 at a Mach number of 0.60. This increment decreased to zero at a Mach number of 0.90 and no beneficial effects were observed at Mach numbers from about 0.90 to about 0.98. At a Mach number of 1.00, no pitch-up occurred at angles of attack up to the maximum angle attained.

2. Drooping the nose  $3^\circ$  on the outer 0.35 semispan of the wing resulted in no increase in lift coefficient at which pitch-up occurred at Mach numbers from 0.60 to about 0.98. No adverse pitching-moment characteristics were observed at angles of attack up to the maximum attained at Mach numbers of 0.98 and 1.00 with the drooped-nose configuration.

3. Combining the fences and drooped nose delayed the adverse pitching-moment characteristics at all Mach numbers where improvements were realized utilizing either of the two configurations individually.

4. The drooped-nose configuration was more effective than the fences in increasing the lift-drag ratios.

5. The installation of vortex generators at the wing leading edge or at the 0.15 chordwise station resulted in little or no improvement in the pitching-moment characteristics.

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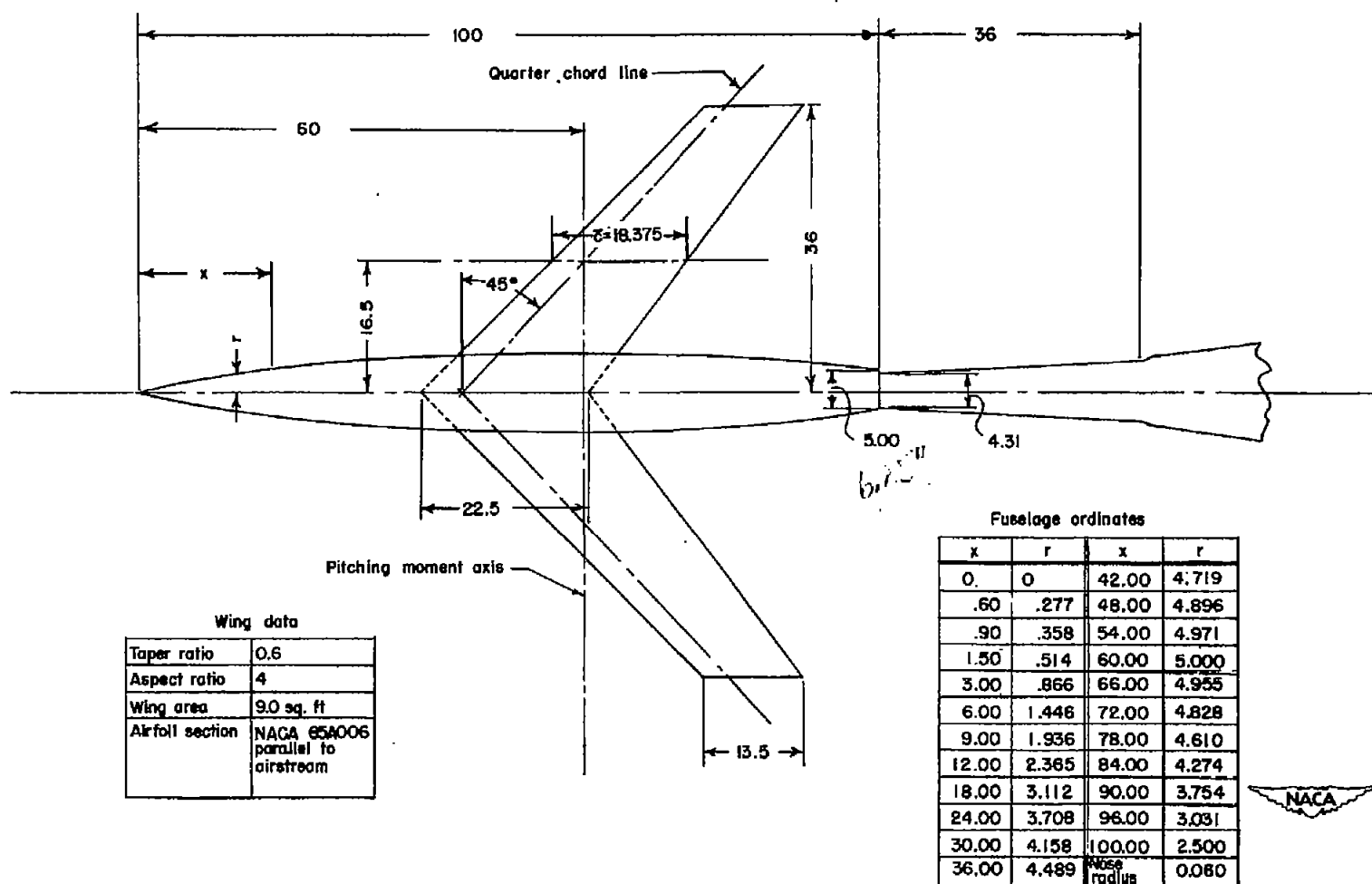


Figure 1.- Principal dimensions of basic model. All dimensions are in inches.

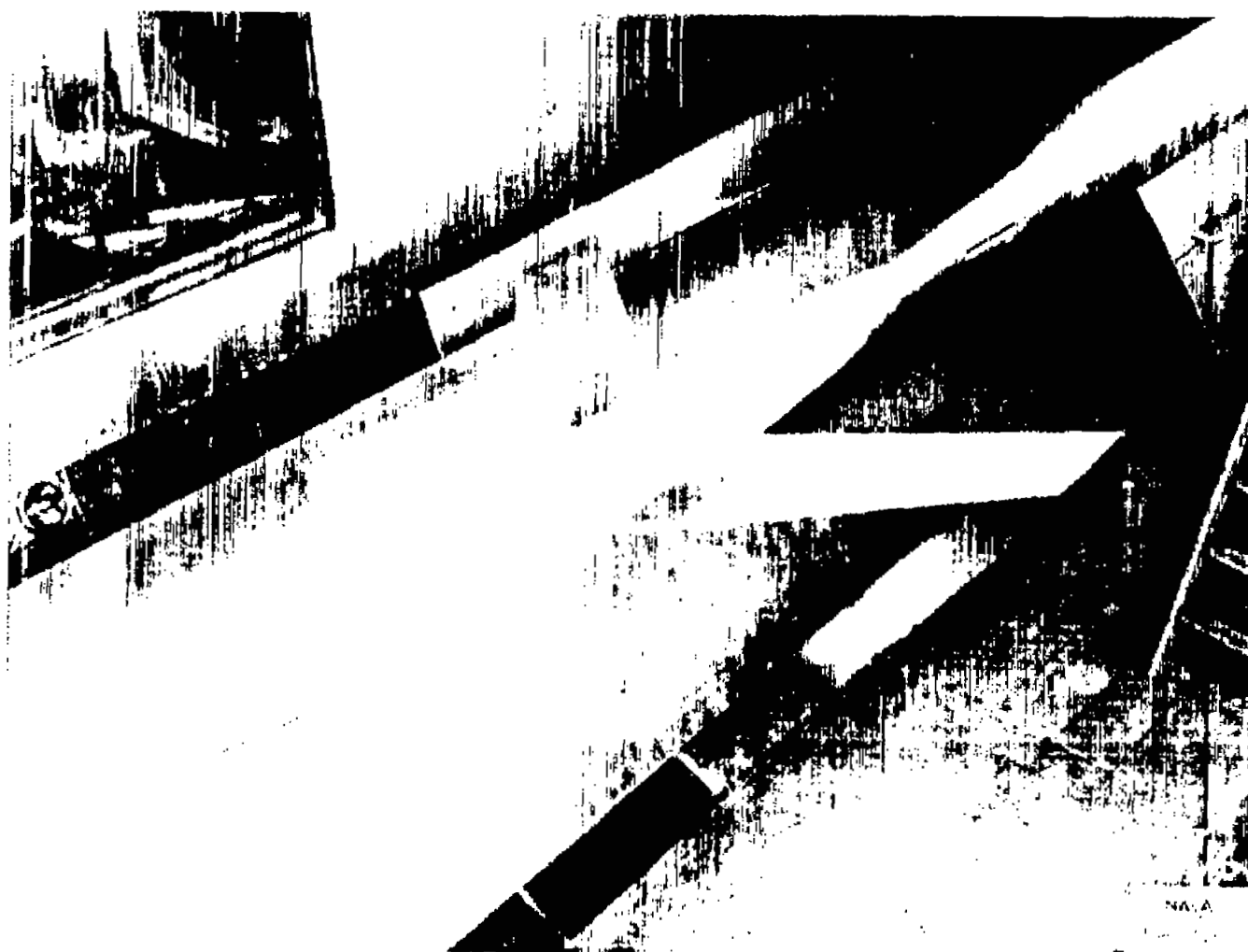


Figure 2.- Photograph of basic model installed in the Langley 16-foot transonic tunnel.

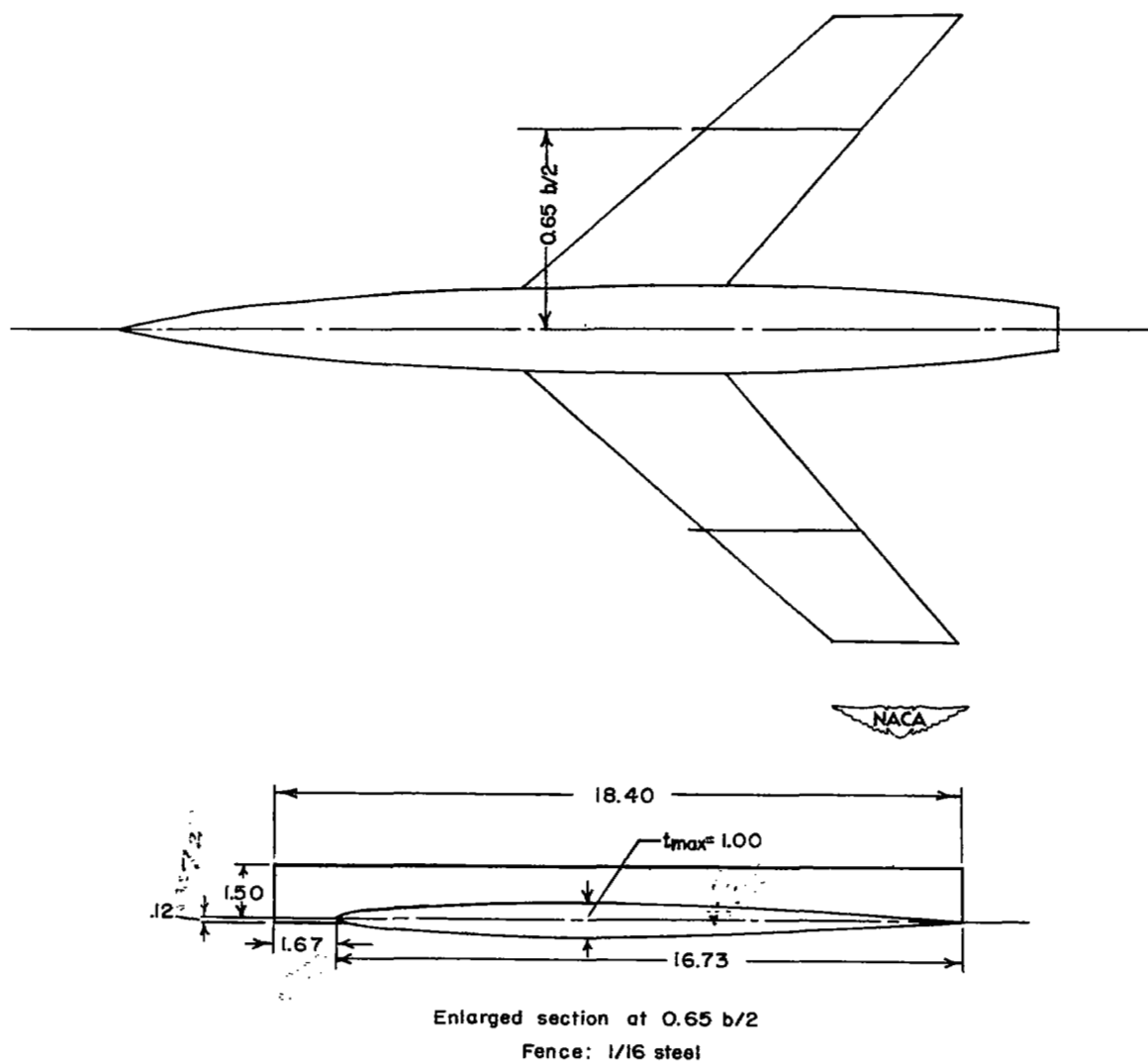
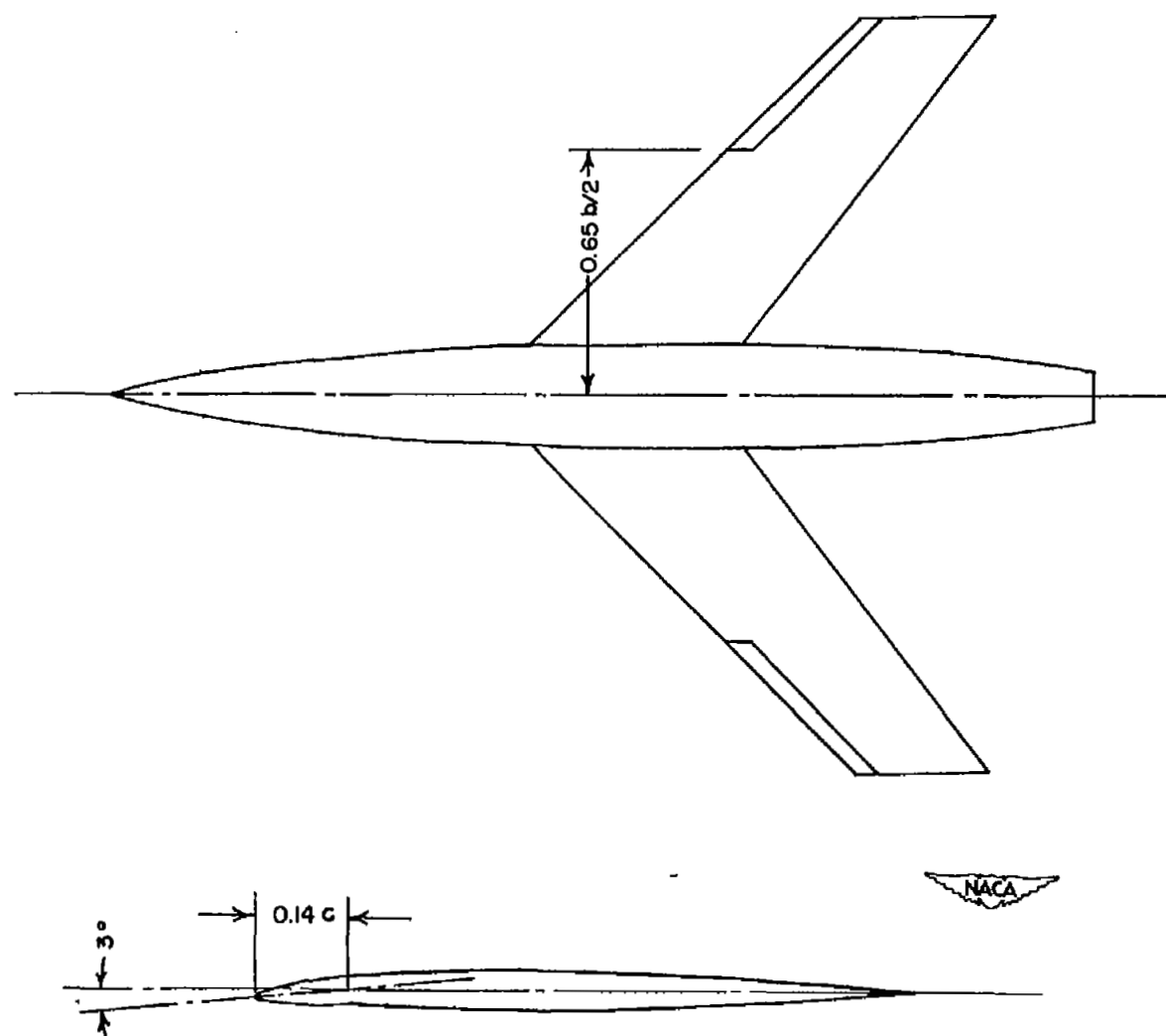


Figure 3.- Sketch showing fences installed on wing. All dimensions are in inches.



Enlarged section outboard of  $0.65 b/2$

Figure 4.- Sketch showing wing with drooped nose.

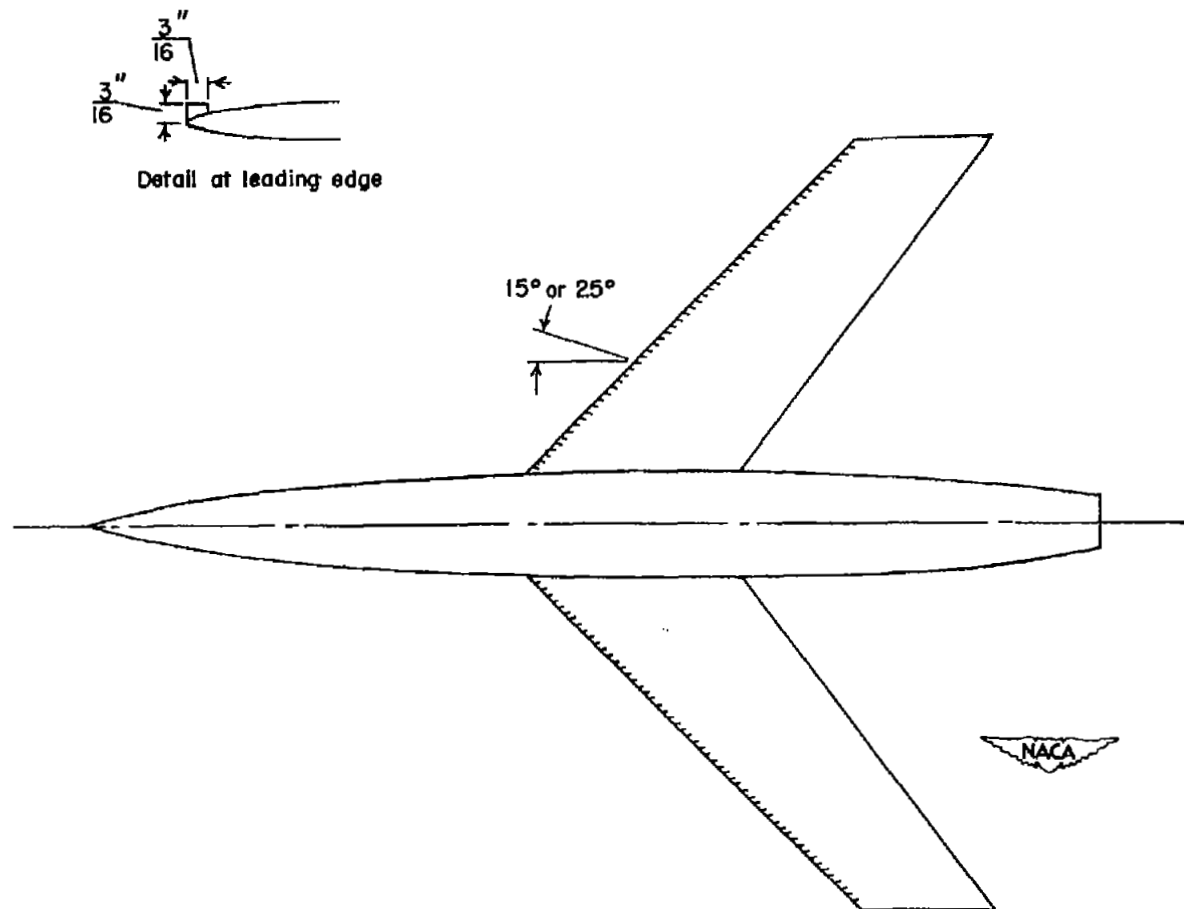


Figure 5.- Sketch showing vortex generators installed at wing leading edge.

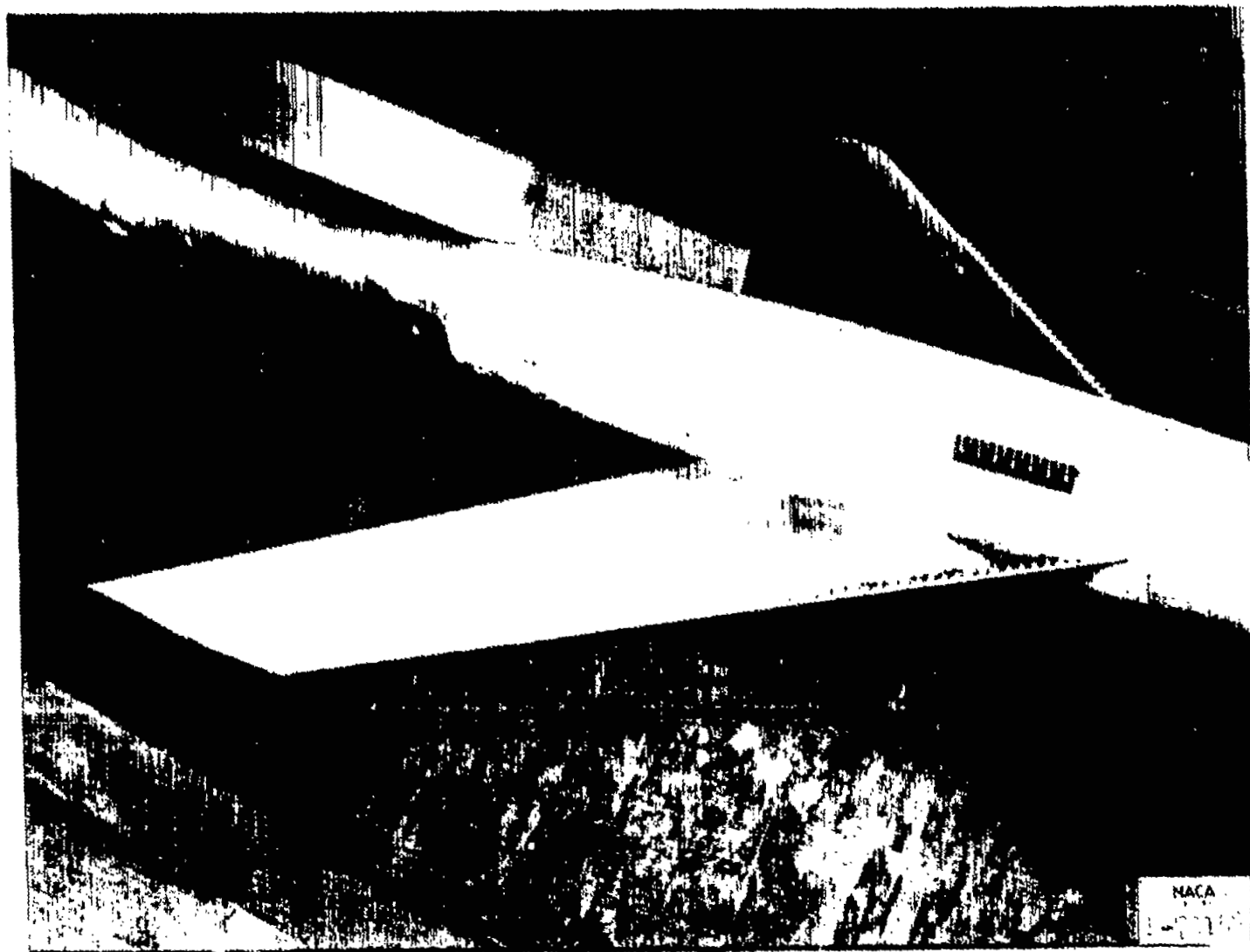


Figure 6.- Photograph showing a typical vortex-generator configuration.

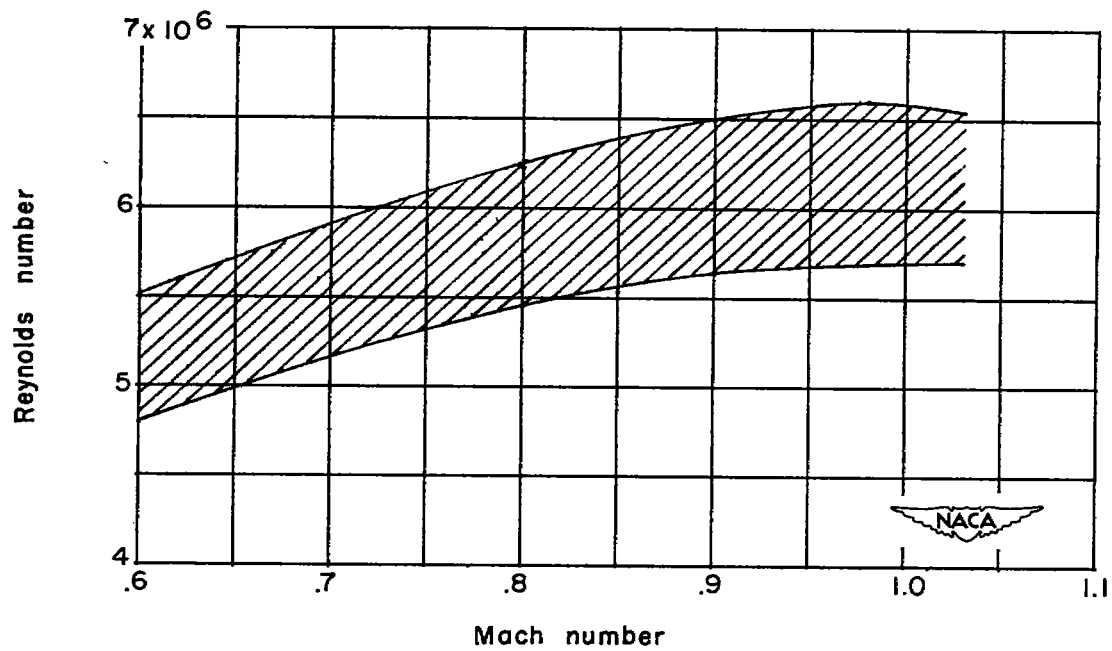


Figure 7.- Variation of test Reynolds number with Mach number.

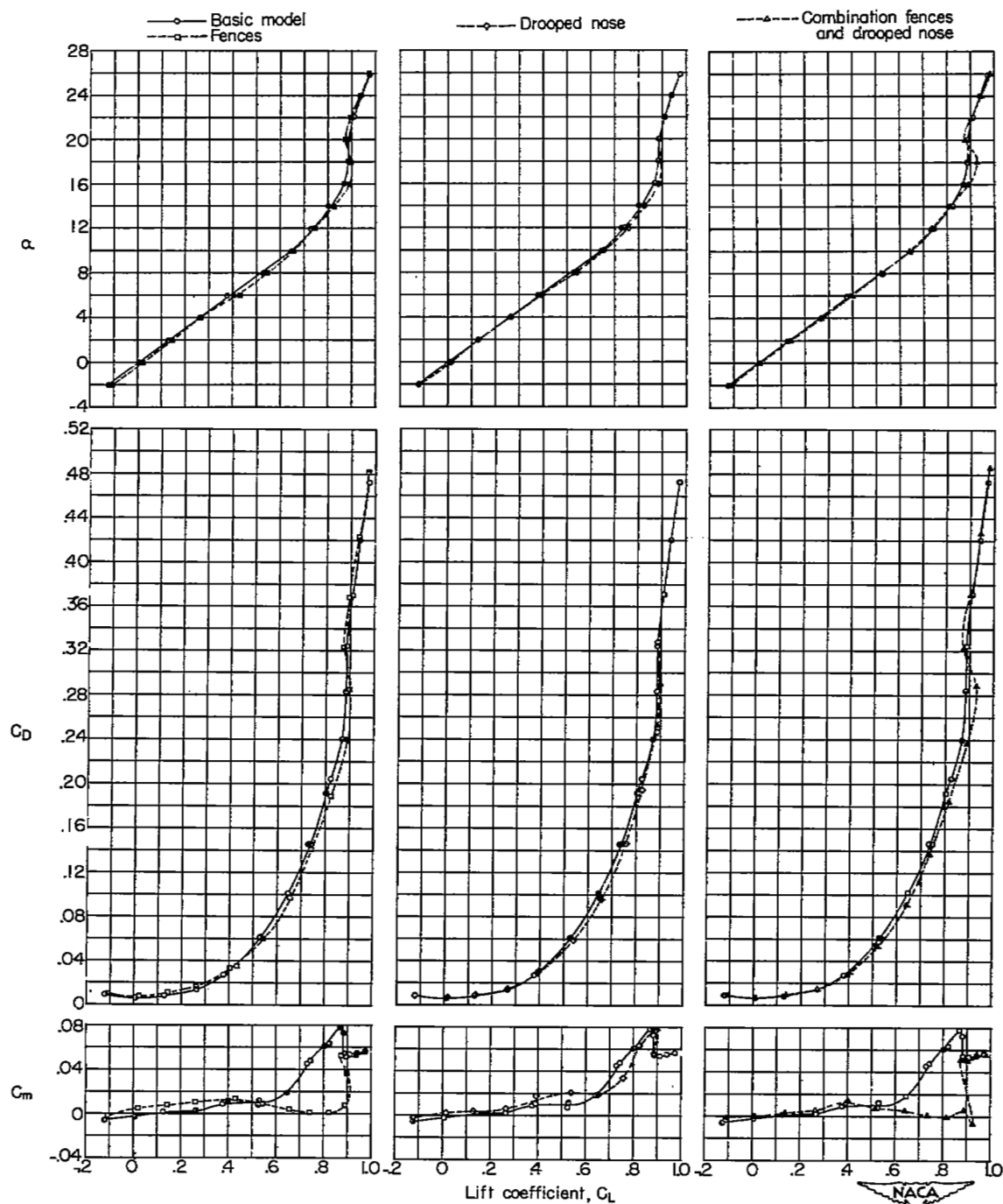
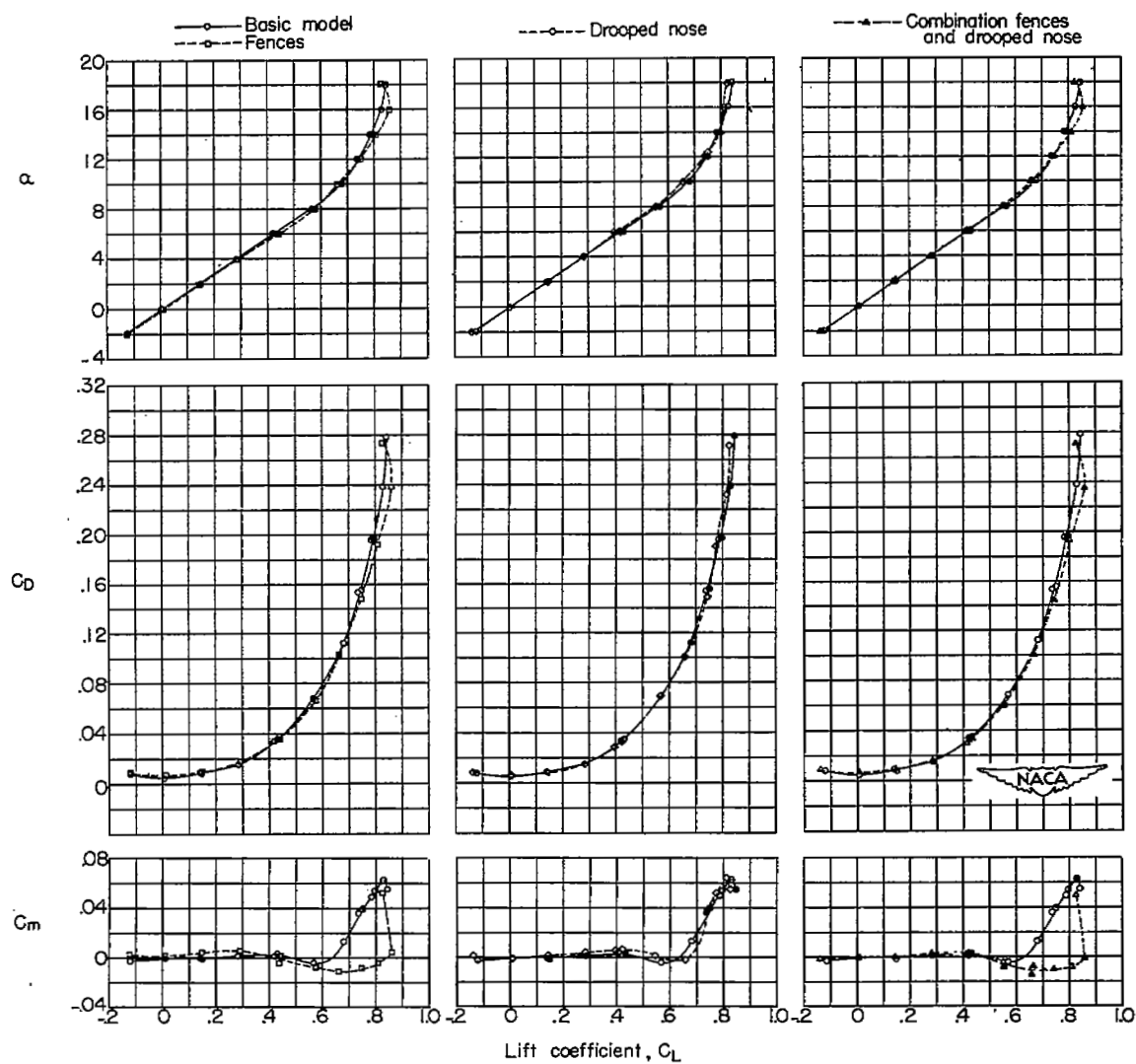
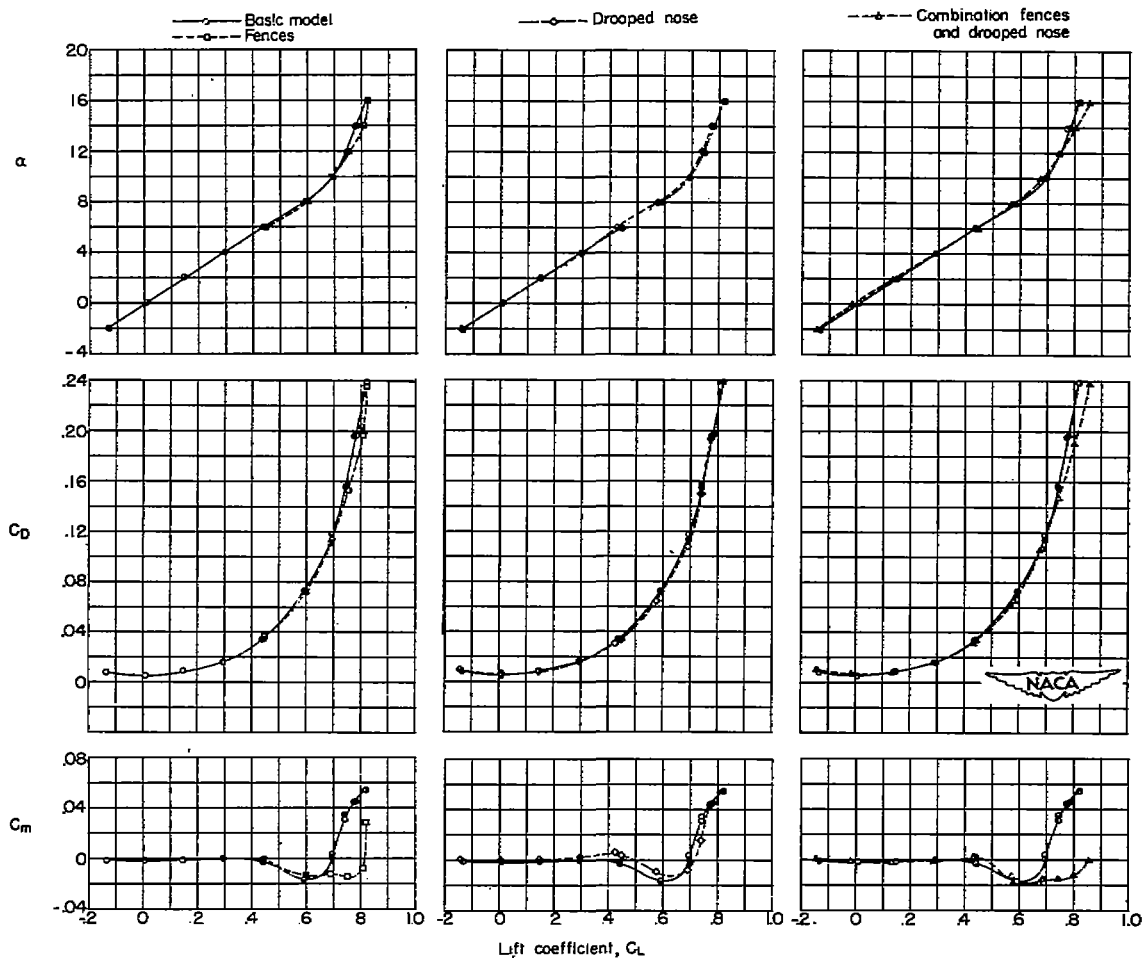


Figure 8.- Lift, drag, and pitching-moment characteristics of model with fences, drooped nose, and combination fences and drooped nose.



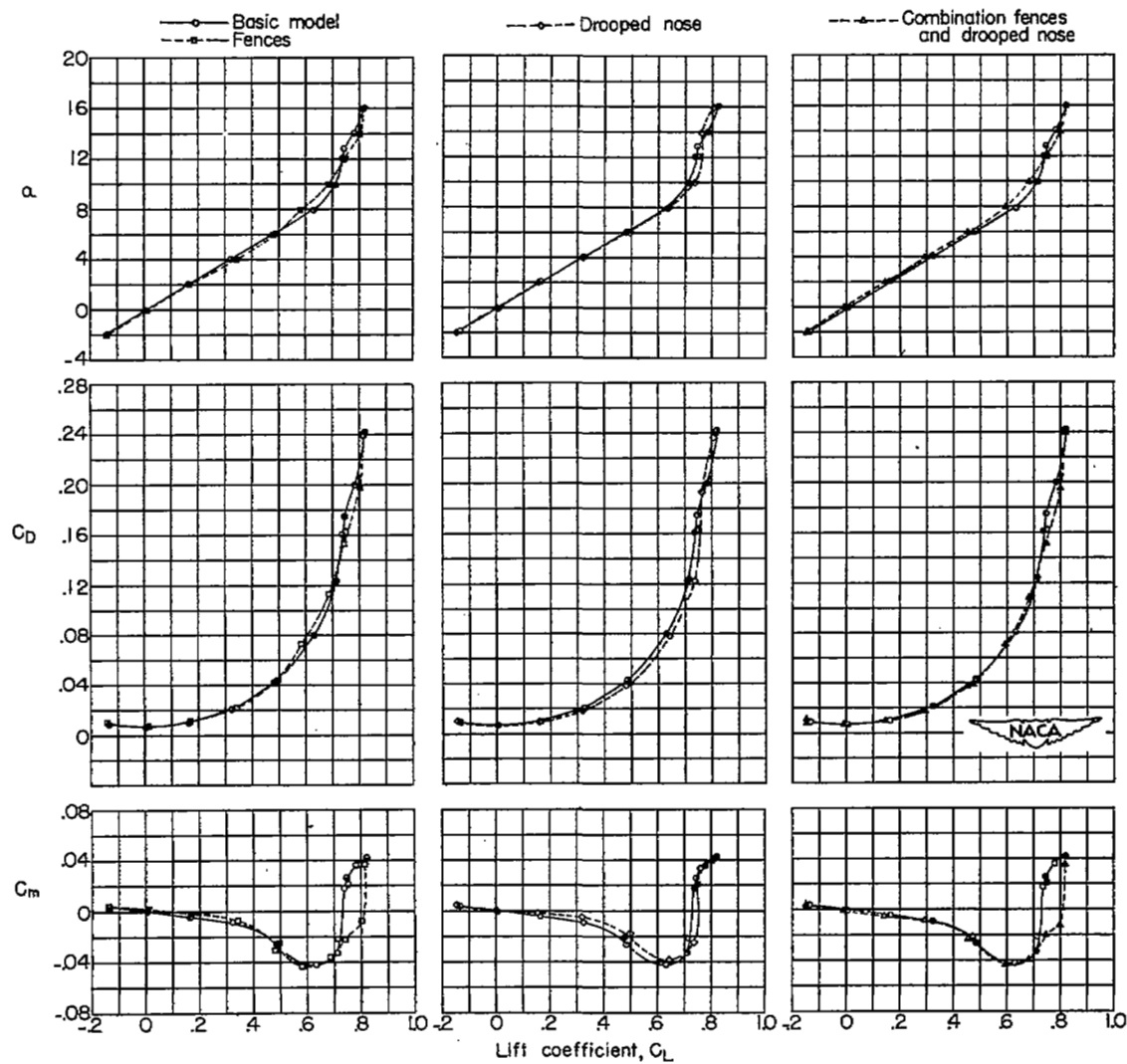
(b)  $M = 0.80$ .

Figure 8.- Continued.



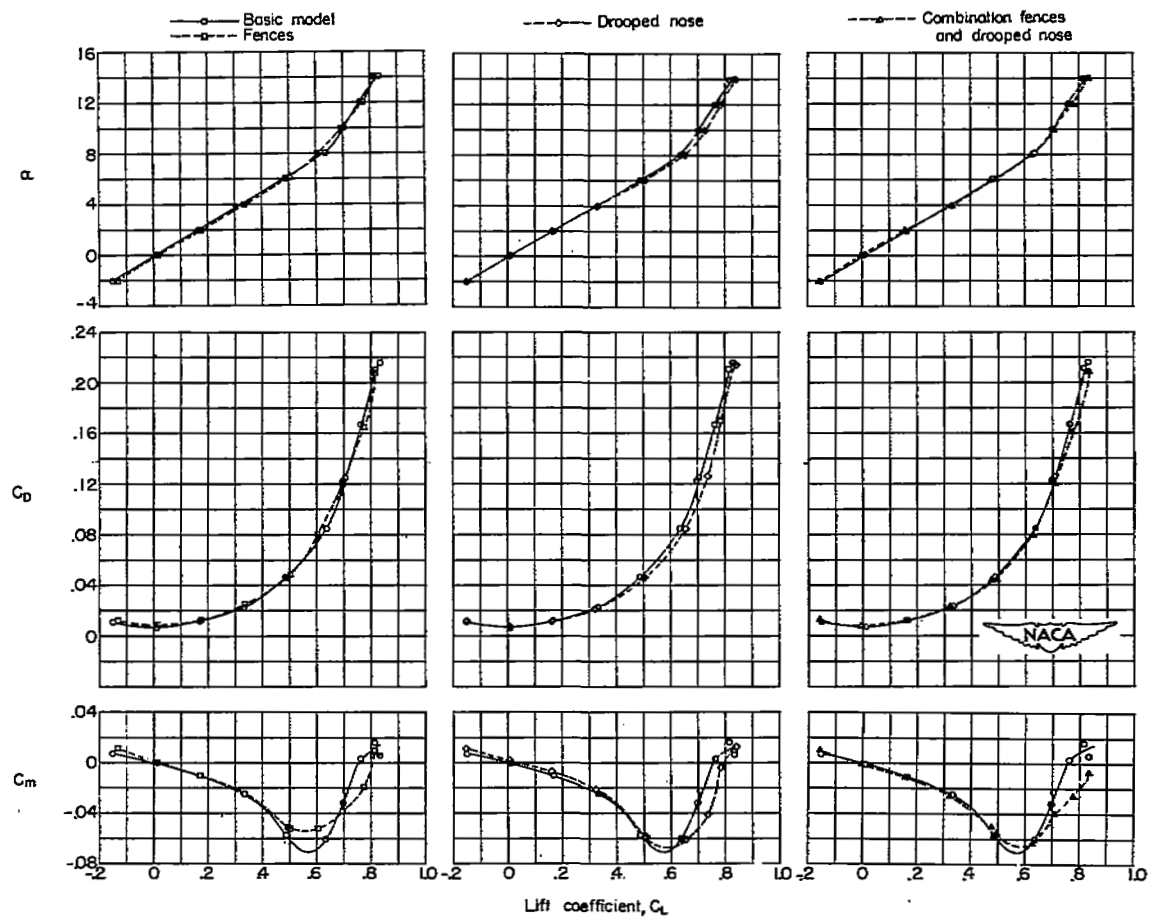
(c)  $M = 0.85$ .

Figure 8.- Continued.



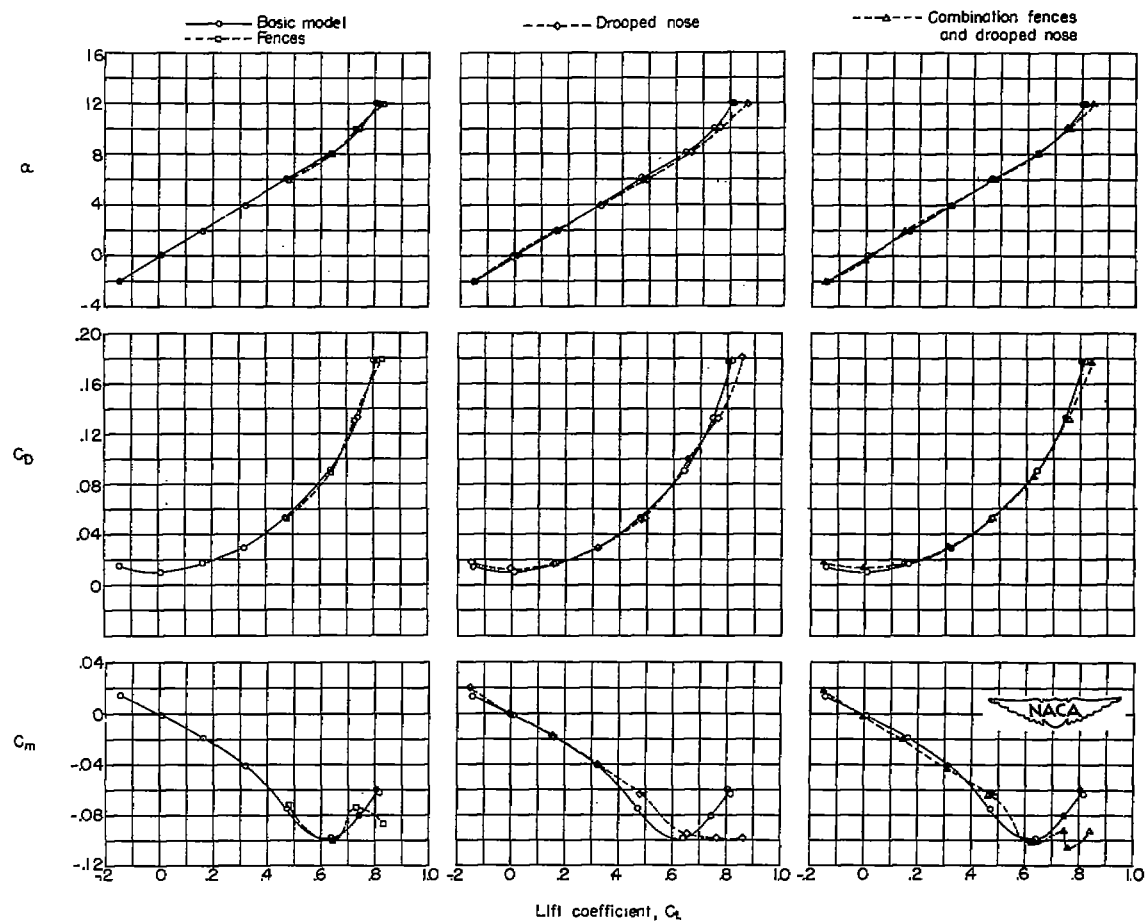
(d)  $M = 0.90$ .

Figure 8.- Continued.



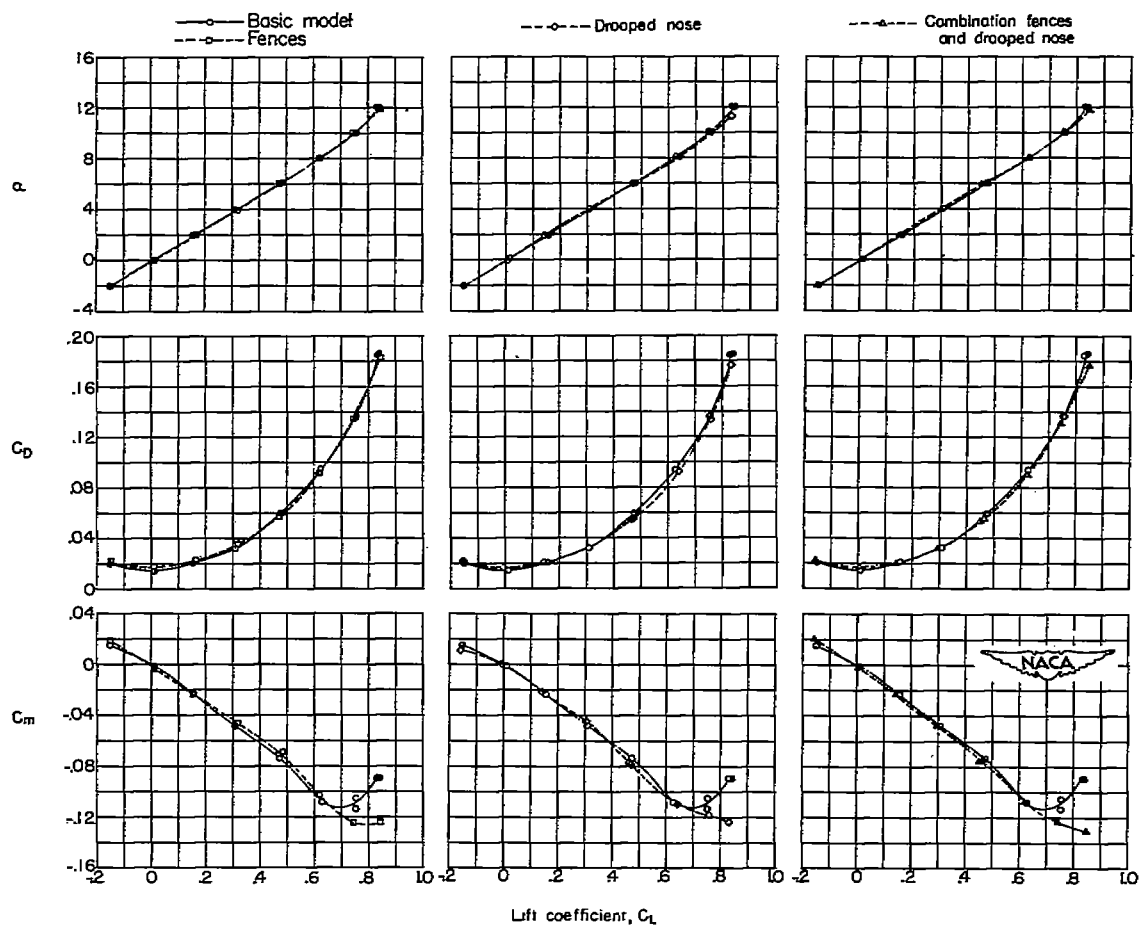
(e)  $M = 0.94$ .

Figure 8.- Continued.



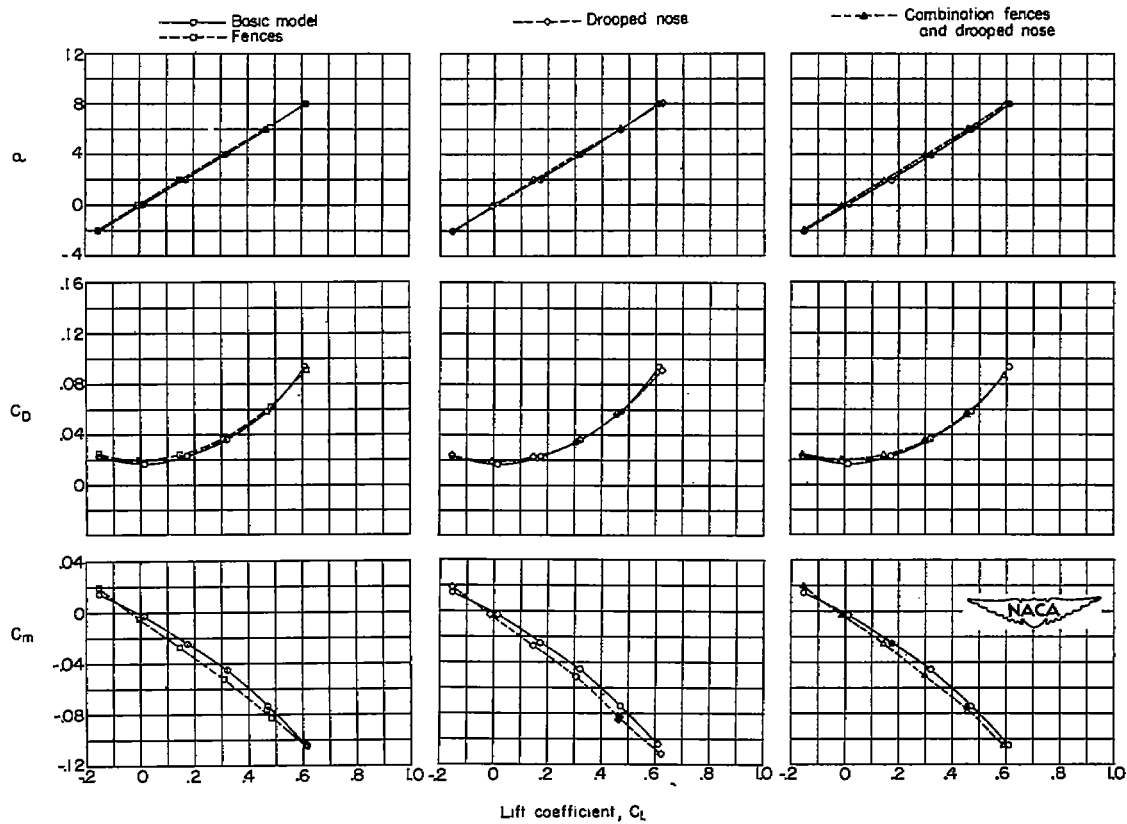
(f)  $M = 0.98$ .

Figure 8.- Continued.



(g)  $M = 1.00$ .

Figure 8.- Continued.



(h)  $M = 1.03$ .

Figure 8.- Concluded.

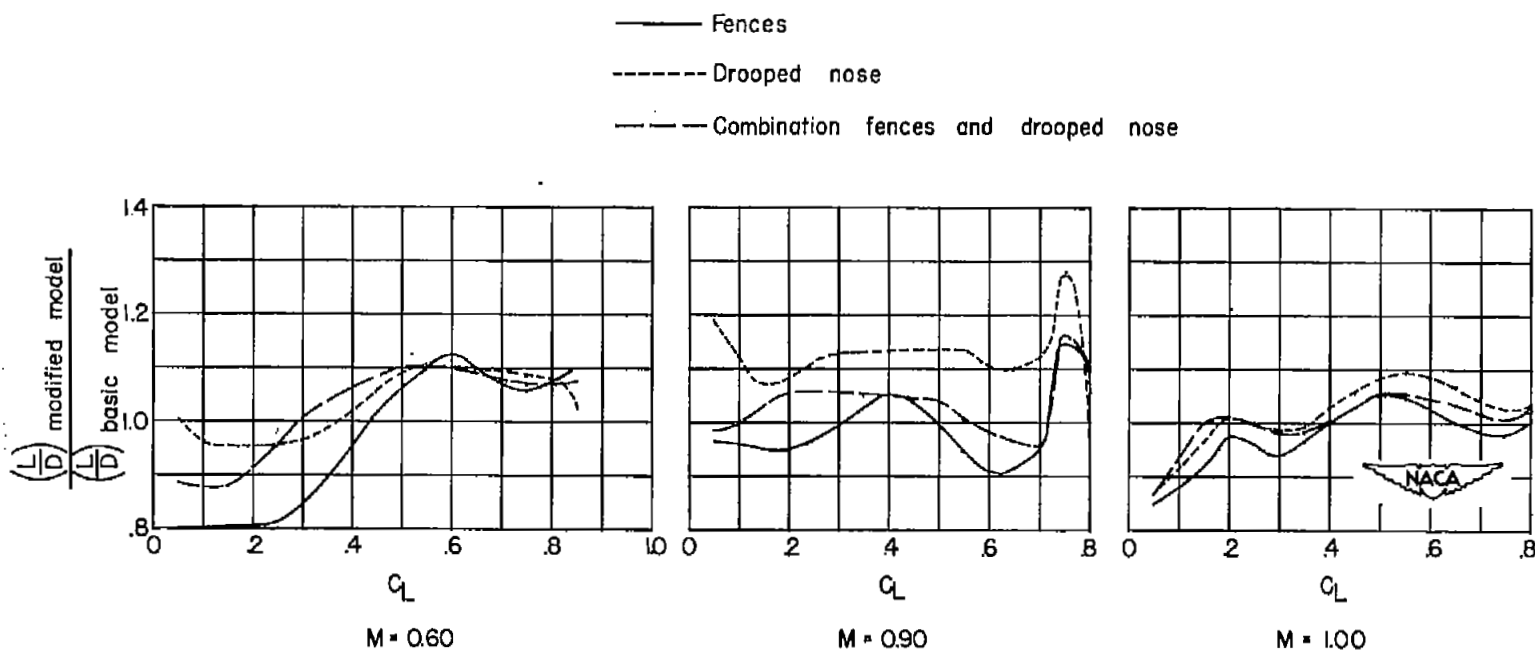


Figure 9.- Effect of fences, drooped nose, and combination fences and drooped nose on the lift-drag ratio.

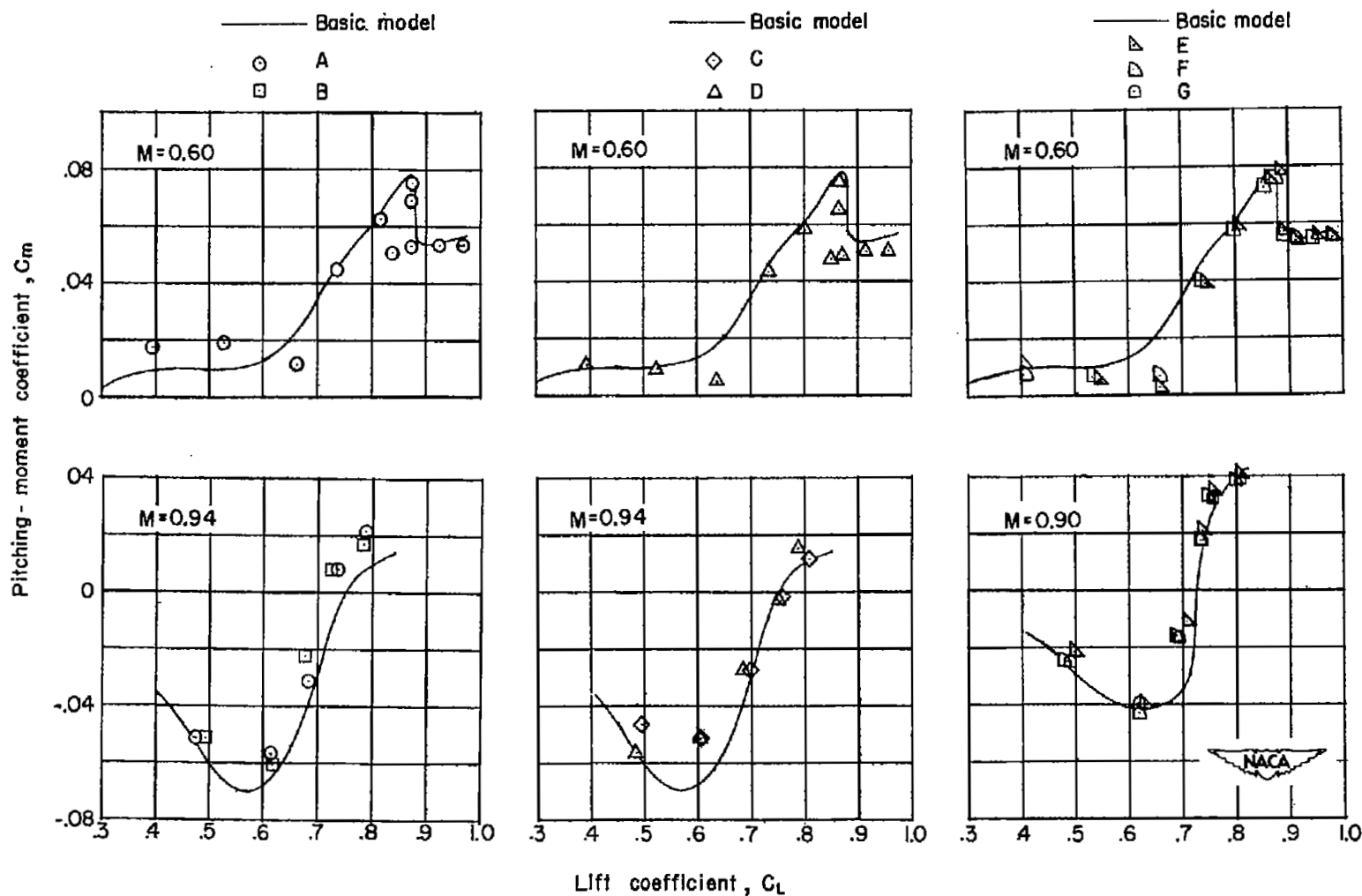


Figure 10.- Variation of pitching-moment coefficient with lift coefficient for model with vortex generators.